AB PDU

Scale-Up and Process Integration of Municipal Solid Waste Conversion Process

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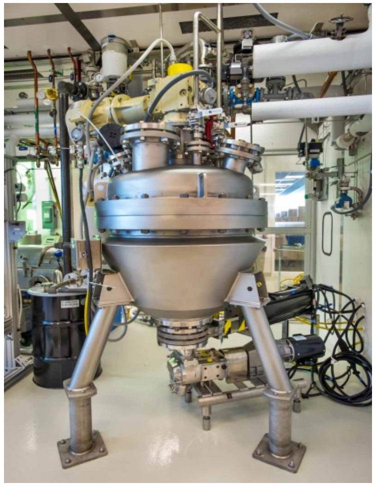
About ABPDU

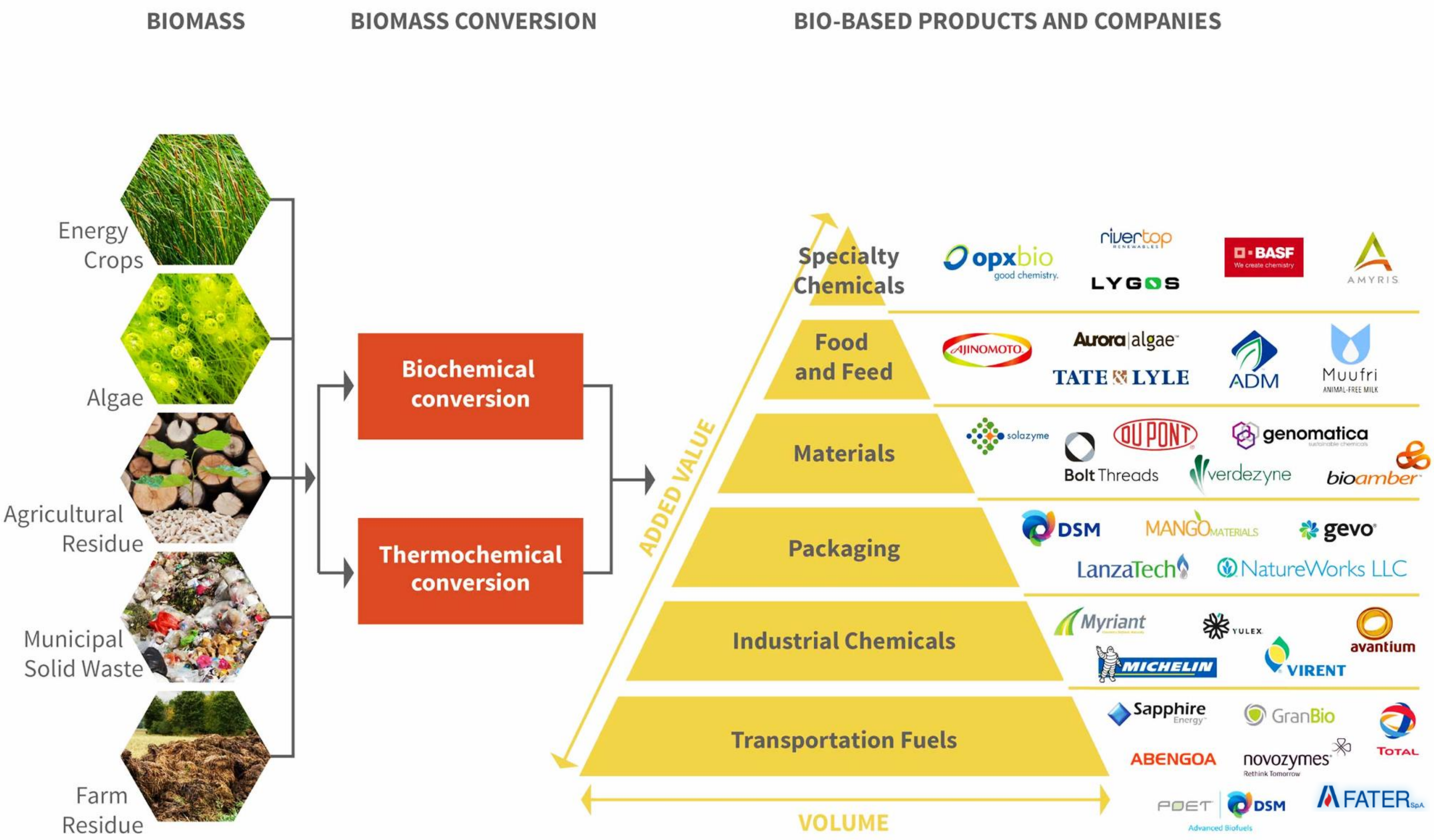
Advanced Biofuels/Bioproducts Process Demonstration Unit (ABPDU) has been fully operational since 2012, collaborating with the Industry, National Labs and Academia to enable early stage advanced biofuels, biomaterials, and biochemicals product and process technologies to successfully scale from the lab to commercial relevance.

Established by American Recovery and Reinvestment Act funds in 2009 – roughly $17 million invested in the 15,000 square foot demonstration Lab

Facility at a Glance: Lab - to - Pilot Scale



Technical Capabilities and Project Types



Today's Focus: Exploring Diversity of Starting Material

Market and regulatory policy are diversifying across renewable feedstocks

Producing:

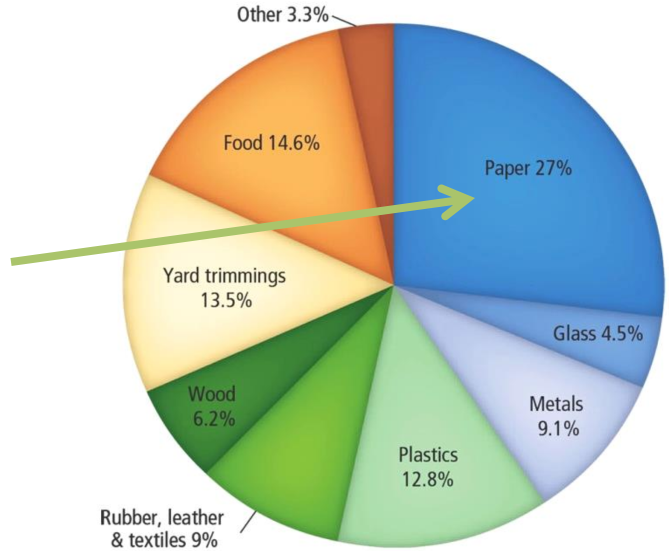
- Alcohols
- Organic acids
- Hydrocarbons
- Terpenes
- Ketones
- Fatty acids
- Lipids
- Proteins
- Enzymes
- Others…

CASE STUDY 1

Lignocellulose / Municipal Solid Waste Blends

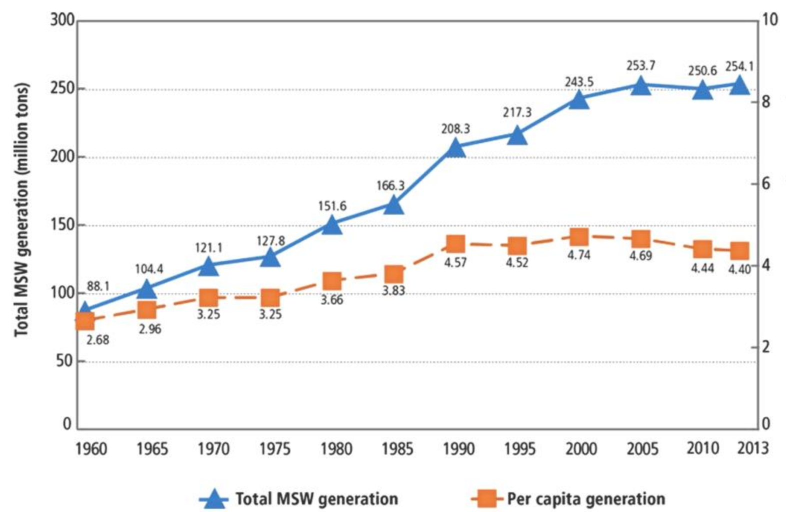
MSW Blends

MSW in this study are non-recyclable:
consisted of aseptic and polycoat containers and packaging, food soiled paper, shredded paper and waxed or coated papers and cardboard. The materials were hand sorted from black bag garbage entering a landfill by **Cascadia Consulting** in Seattle WA.



Total MSW Generation (by Material), 2013
254 Million Tons (before recycling)

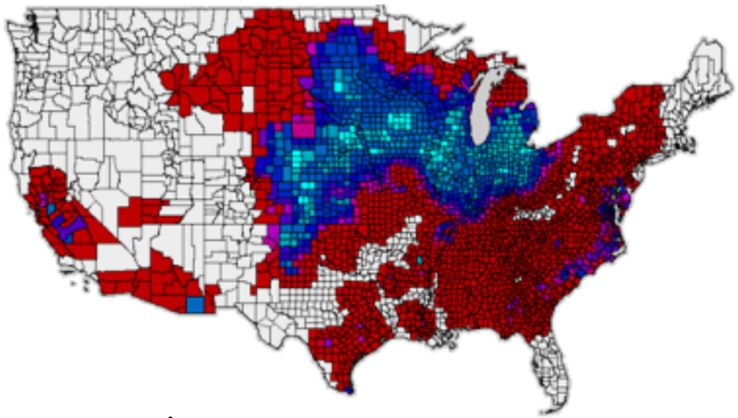
- **Advantages**
  - Year-round availability
  - Low or negative cost
  - Collection infrastructure
  - Abundance and renewable
- **Disadvantages**
  - Highly variable
  - Low quality
    - Sorting
    - Upgrading



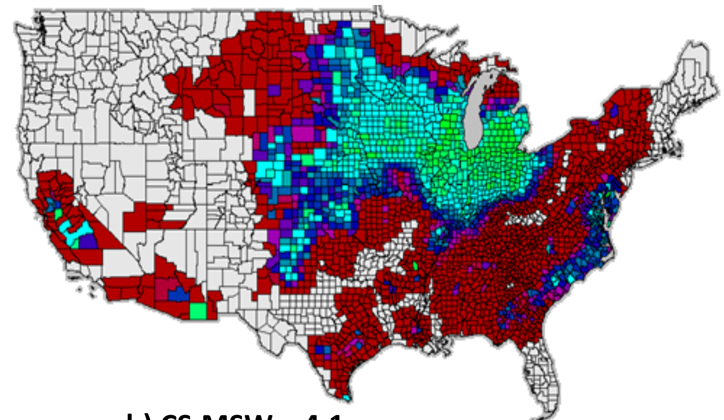
MSW Generation Rates, 1960-2013

Source: http://www.epa.gov/epawaste/nonhaz/municipal/index.htm

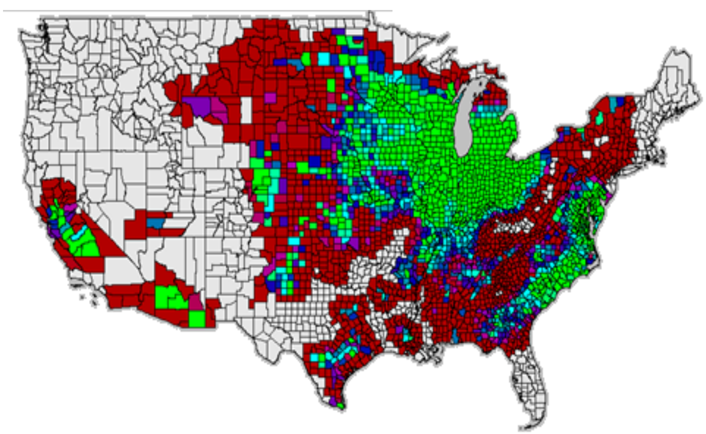
Idaho National Lab's Least-Cost-Formulation Output for Midwest MSW/CS Blends



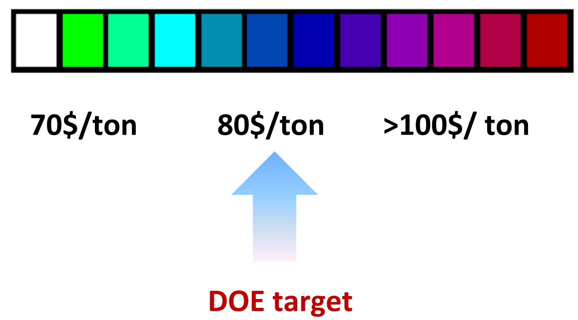
a) Corn Stover



b) CS:MSW = 4:1



c) CS:MSW = 1:1



Sun et al., 2015, Bioresour Technol, 186: 200-206

MSW/CS blends have the great potential to meet the "cost target"

MSW/CS Blends Compositions

CS/MSW ratio	Ash (%)	Glucan (%)	Xylan (%)	Glucan+Xylan (%)
10:0	3.0	33.2	20.8	50.8
9:1	3.8	35.5	19.7	55.2
8:2	4.6	37.7	18.6	56.3
7:3	5.4	40.0	17.6	57.6
6:4	6.2	42.2	16.5	58.7
5:5	7.0	44.5	15.4	59.9
0:10	10.9	50.8	10.0	60.8

MSW/CS blends have the great potential to meet "quality requirements"

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Sun et al., 2015, Bioresour Technol, 186: 200-206

A Wider Range of Feedstock Screening

Besides CS/MSW, more blends were studied at small scale：

16 Blends 2015 (%)					
No.	Corn Stover	Switchgrass	Grass clippings	MSW	Abbr.
1	90		10		CG9:1
2	80		20		CG8:2
3	70		30		CG7:3
4	60		40		CG6:4
5		90	10		SG9:1
6		80	20		SG8:2
7		70	30		SG7:3
8		60	40		SG6:4
9	90	10			CS9:1
10	80	20			CS8:2
11	90			10	CM9:1
12	80			20	CM8:2
13	70			30	CM7:3
14		90		10	SM9:1
15		80		20	SM8:2
16		70		30	SM7:3

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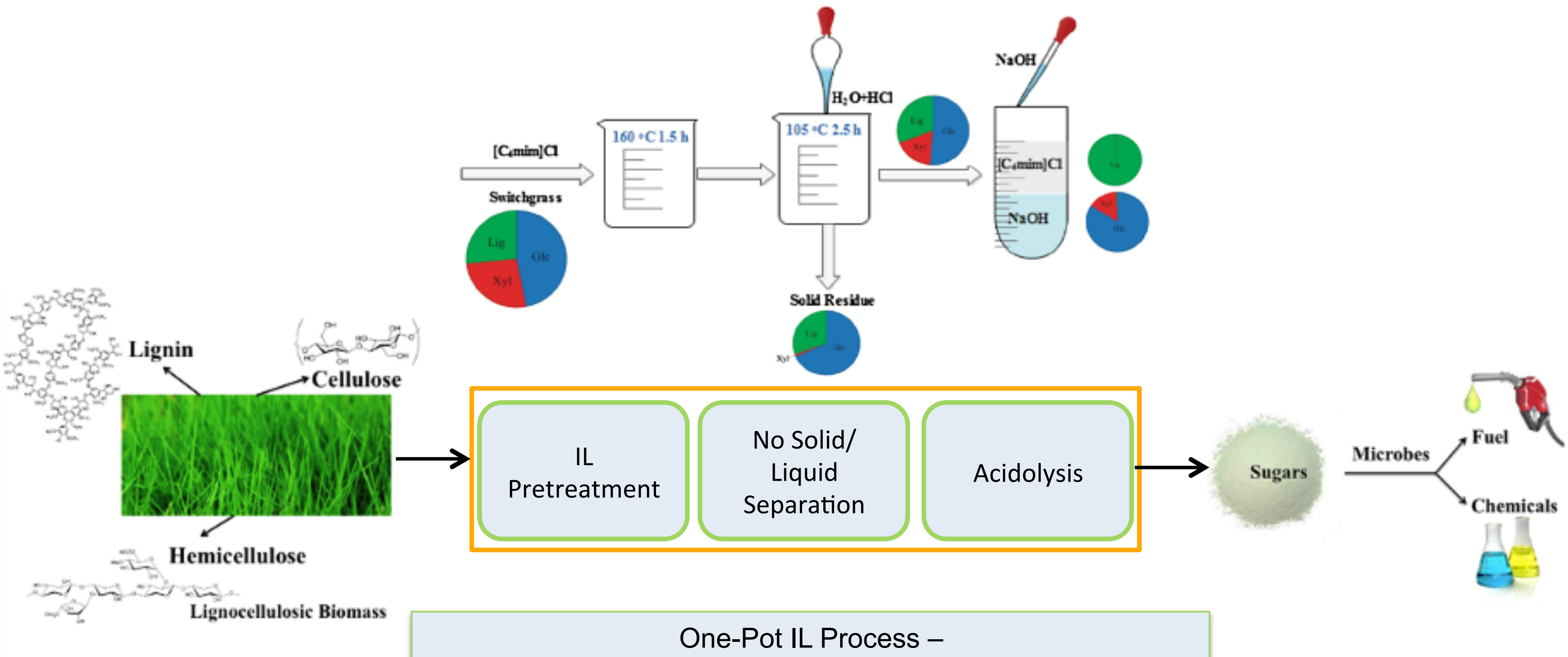
Method: Ionic Liquid Acidolysis Process



One-Pot IL Process –
Enzyme Free and Wash Free

Sugar Extraction, IL and Lignin Recovery

Universal Feedstock Utilization

Sun et al., 2013, Biotechnology for Biofuels, 6:39

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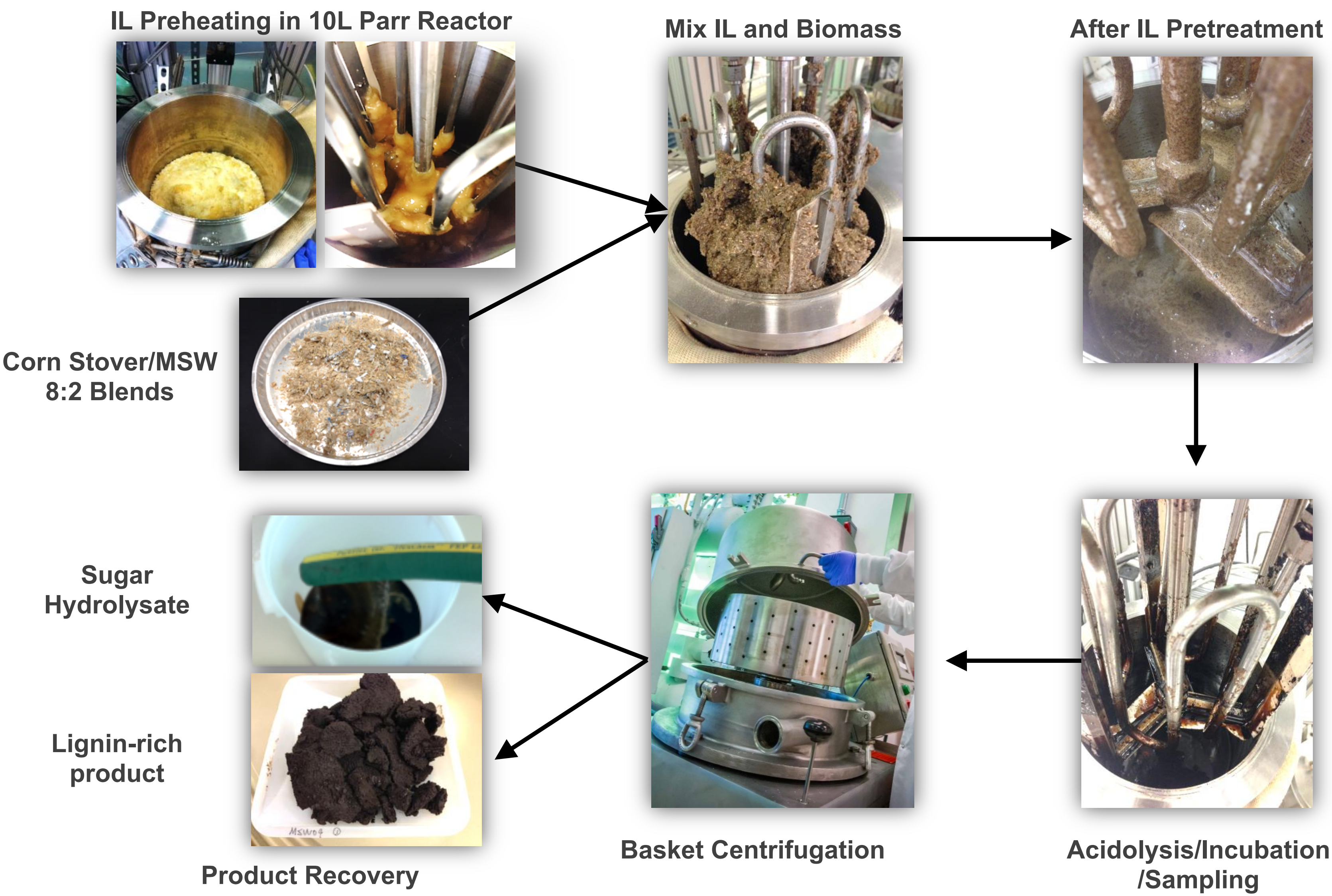
Ionic Liquid Acidolysis Scale-up Process Flow

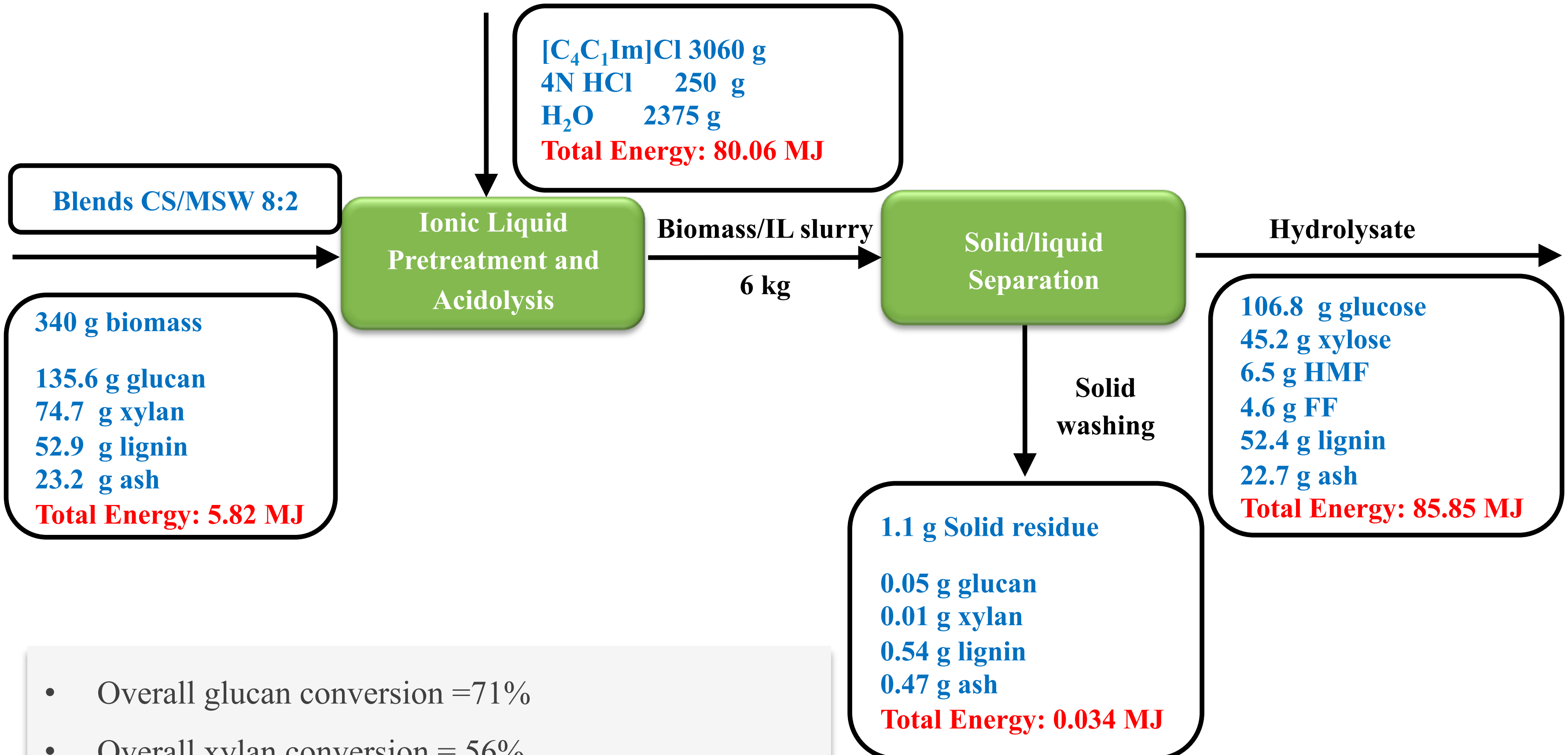


Sugar Yield Summary

Run	Ionic Liquid	Solid Loading	T (°C)/t (h)	Glucose Yield (%)	Xylose Yield (%)	Solid Recovery (%)
1	$[C_4C_1Im]Cl$	10	140/2	42.01	55.69	16.94
2	$[C_4C_1Im]Cl$	10	150/2	64.74	42.00	5.88
3	$[C_4C_1Im]Cl$	10	160/2	70.90	50.00	0.36
4	$[C_4C_1Im]Cl$	15	160/2	63.29	40.96	2.77
5	$[C_4C_1Im]Cl$	10	120/2	53.66	50.97	13.57
6	$[C_2C_1Im]Cl$	10	120/2	44.47	46.89	21.34
7	$[C_2C_1Im]Cl$	10	140/2	53.58	35.16	11.66
8	$[C_2C_1Im]Cl$	10	160/2	57.80	35.84	6.80

- Feedstock: CS/MSW 8:2, Non-recycle paper mix
- Ionic liquids:
  1-Ethyl-3-methylimidazolium chloride ($[C_2C_1Im]Cl$)
  1-Butyl-3-methylimidazolium chloride ($[C_4C_1Im]Cl$)

Mass and Energy Balance



- Overall glucan conversion =71%
- Overall xylan conversion = 56%
- Overall lignin recovery from solid stream = 1%

Case 1 Summary

- Successfully demonstrated 200-fold scale up of **MSW blends** IL acidolysis.

- Developed an integrated process for **ionic liquid based deconstruction** technologies for MSW blends conversion.

- The scale up attempt will leverage the opportunity towards a cost-effective MSW blends conversion technology.

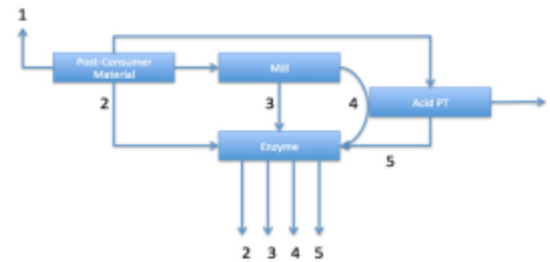
CASE STUDY 2

Post-consumer Absorbent Hygiene Products (AHPs)

Case 2: The FATER – ABPDU Partnership

- ABPDU has been developing and validating an integrated waste-to-energy process under a DOE **Work-For-Others** (WFO) Agreement with FATER.
- Key outcomes indicate that post-consumer absorbent hygiene products (AHPs) can be readily and economically converted -- without using harsh or expensive pretreatment routes -- to sugars and fuel intermediates.

Conversion of FATER MSW



AHPs Collection
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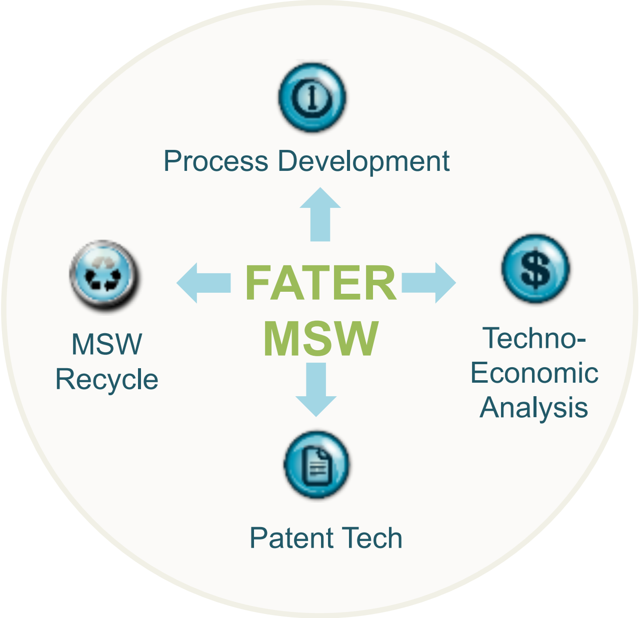
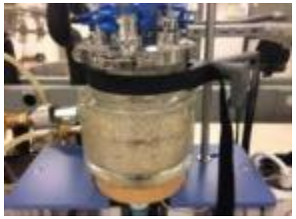
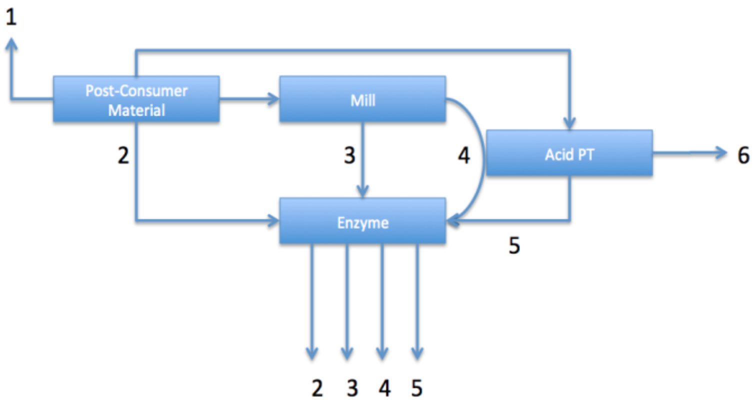
Transport
↓
Sterilization
↓
Plastic Separation
↓
Cellulose Recycle



Unit Operation
↓
Pretreatment
↓
Enzymatic Saccharification
↓
Fermentation
↓
Scale Up



Thermochemical Pretreatment + Enzymes



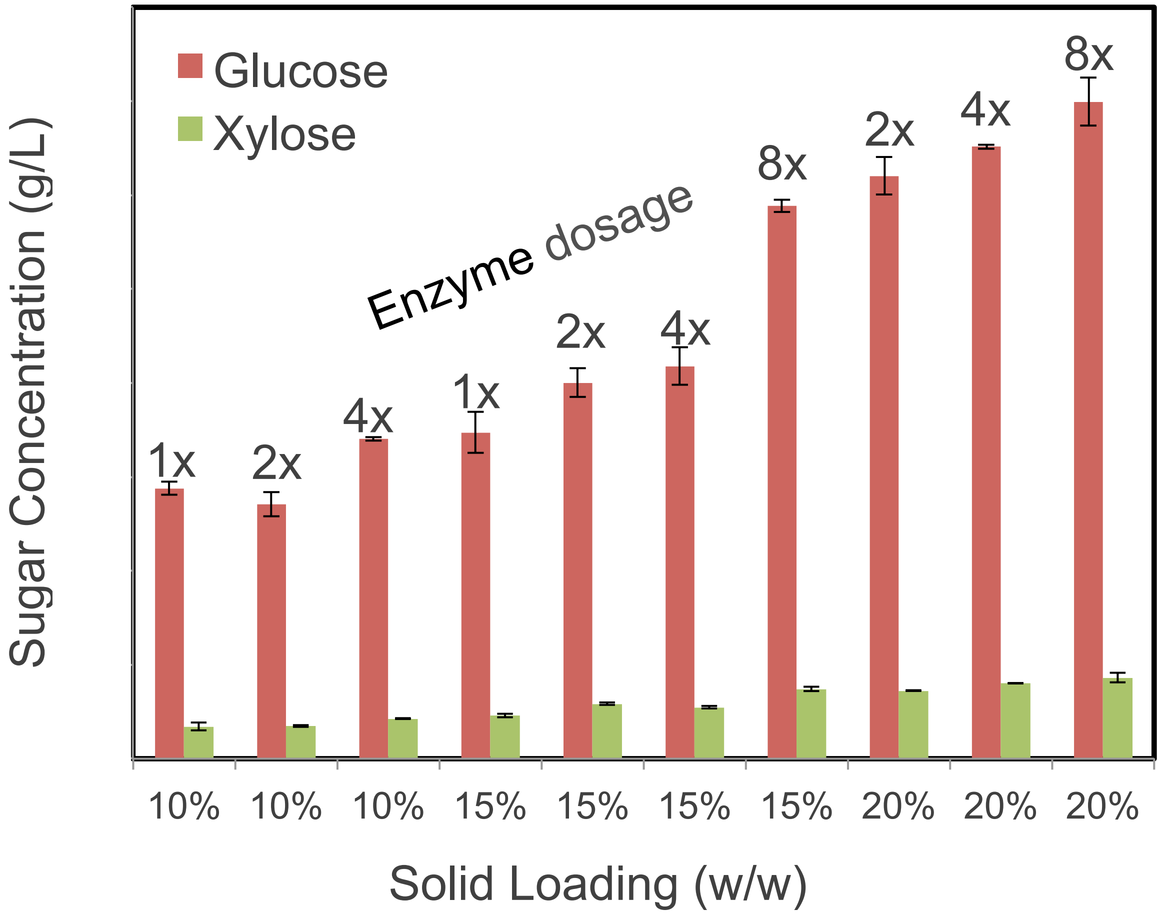
Defining the Deconstruction Routes

15 ml Incoloy Tube Reactors

Fluidized Sand Bath

- **Dilute acid pretreatment**: 1% sulfuric acid, 120°C, 15 min, 10% solid loading
- **Hydrothermal pretreatment**: 120°C, 15 min, 10% solid loading

Lab-scale Hydrolysis Process Optimization

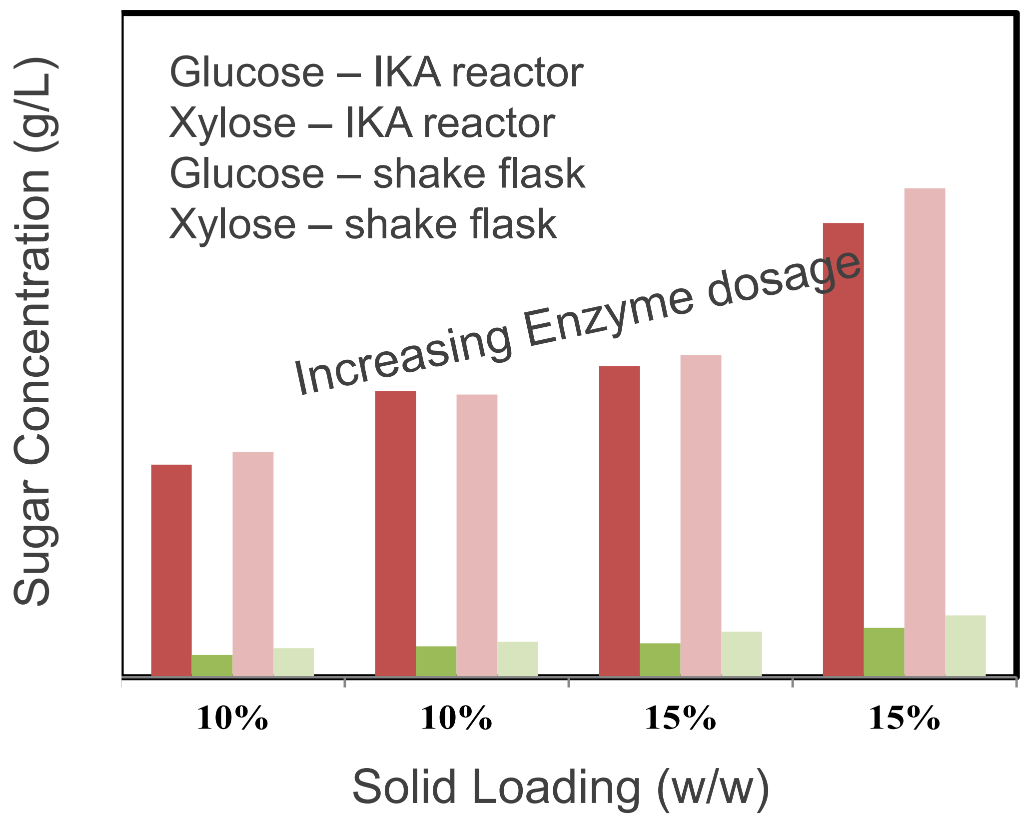


- Higher solid loading (dry basis) resulted in higher sugar concentrations
- Larger enzyme dosage increased sugar yields

Bench-Scale Enzymatic Saccharification

Efficient mixing key to reproducible, scalable hydrolysis of actual AHP materials

Optimized Hydrolysis Performance at Bench Scale



- Enzymatic saccharification was scaled up 50 times
- High consistency of sugar yield between flask scale and reactor was observed

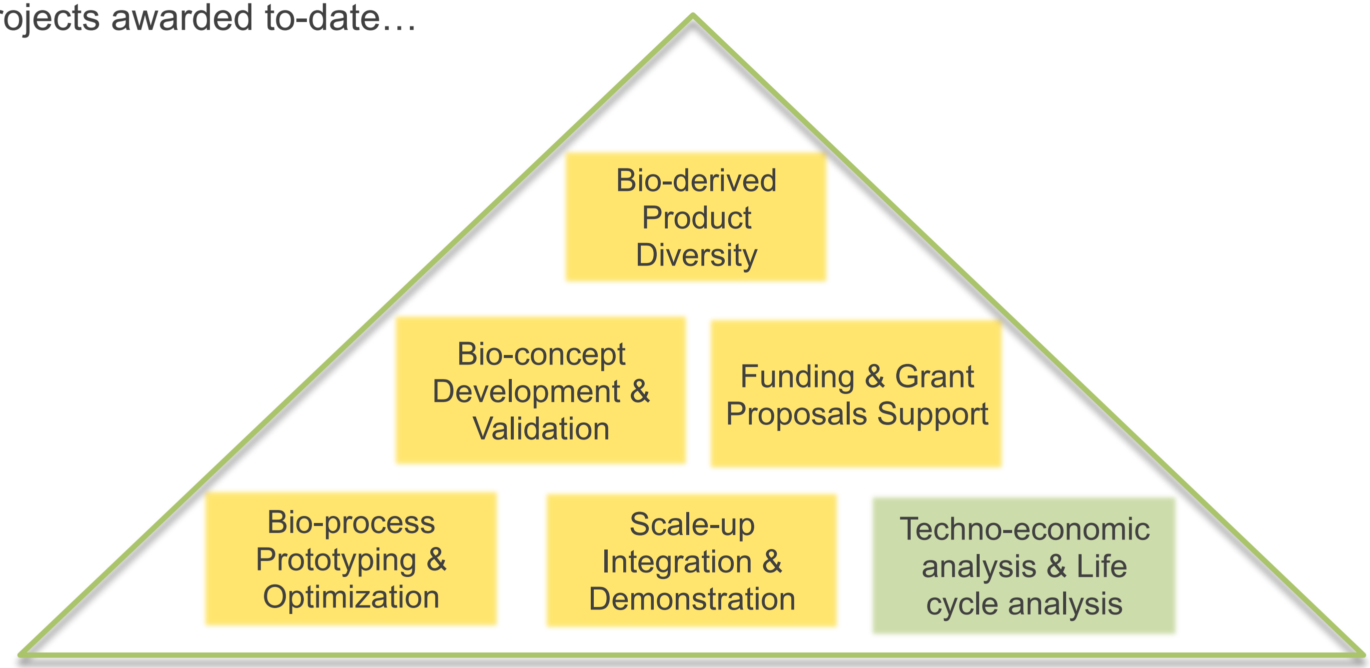
Case 2 Summary

Two Potential Commercialization Routes

- Feedstock
  - Enzyme-compatible cellulose-rich material for integration with cellulosic ethanol or chemical producers
- Sugar product
  - Production of sugar monomers and packaging / distribution to users in traditional first-gen starch- and sugar-based fermentation manufacturers

Working With ABPDU

- Sponsors can receive title or exclusive licenses to inventions and IP generated under **“Work for Others”** or **“CRADA”** contracting at ABPDU.
- More than 30 FOA proposals developed in partnership with small businesses as leads - 18 projects awarded to-date…



Acknowledgements

- **DOE EERE** (Energy Efficiency and Renewable Energy) **– BETO** (BioEnergy Technologies Office)
- **Joint BioEnergy Institute**
- **Idaho National Laboratory**
- **Sandia National Laboratory**
- **FATER** Corporate
  - Founded in 1958 by Angelini. Since 1992, a joint-venture of Procter & Gamble and Angelini
- **Staff** of ABPDU

THANK YOU

<u>Contact info</u>

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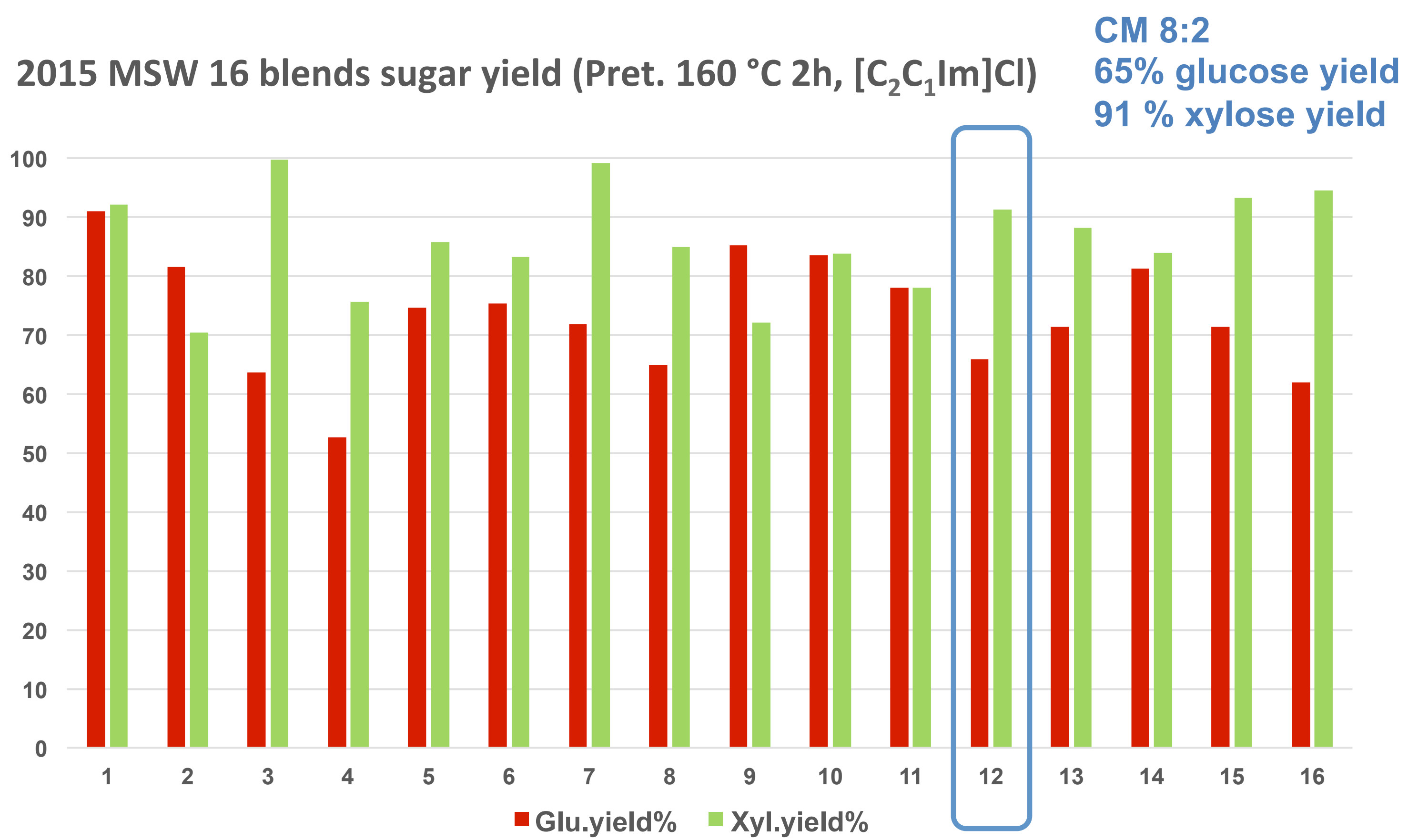
Small Scale Screening Results



Ionic liquid - $[C_2C_1Im]Cl$: 1 -Ethyl-3-methylimidazolium chloride

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